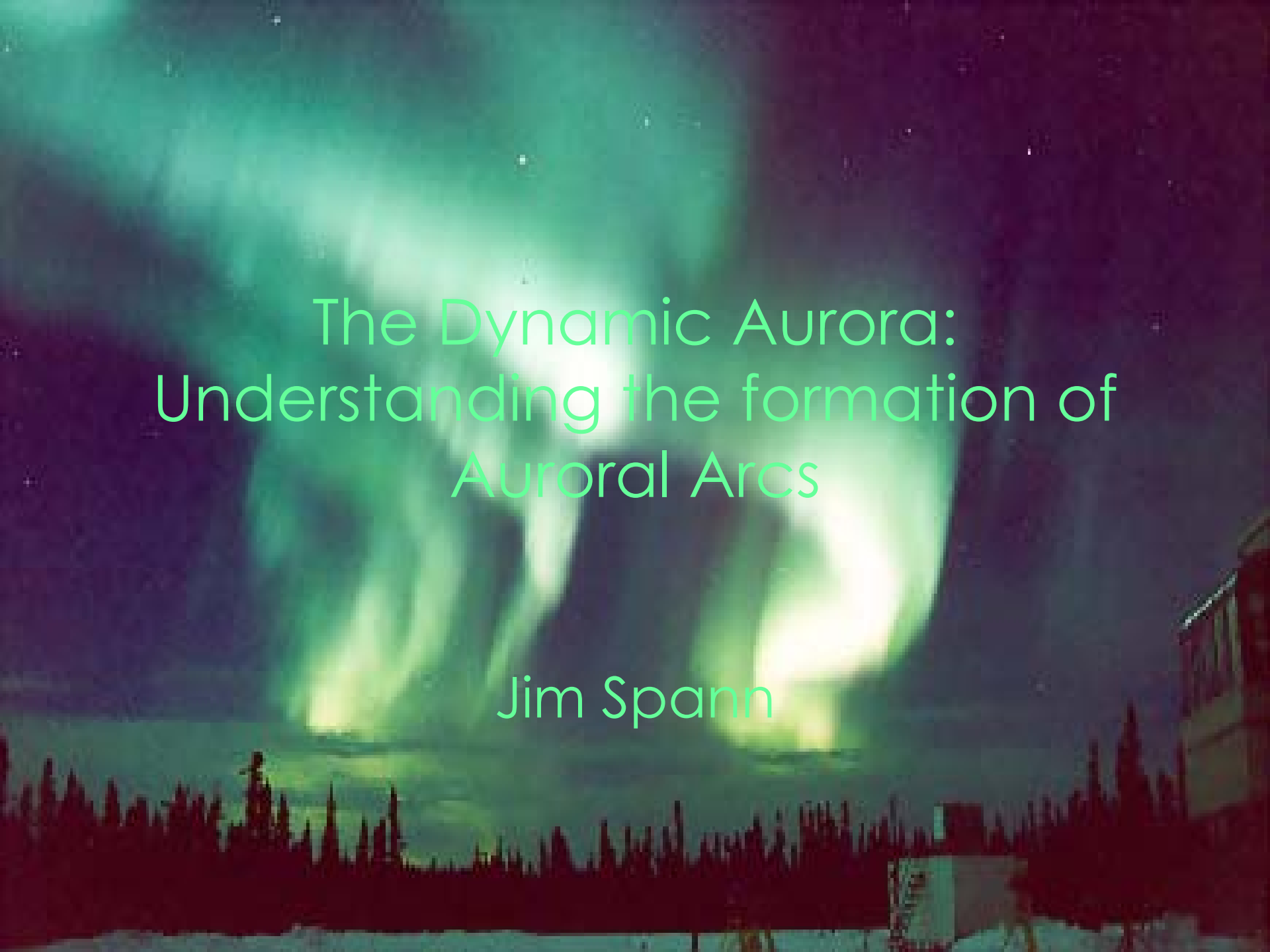


The Dynamic Aurora: Understanding the formation of Auroral Arcs

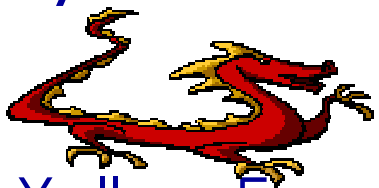
Jim Spann

The Dynamic Aurora: Understanding the formation of Auroral Arcs

Jim Spann

- early references/folklore
- historical background
- views of aurora
- what we know about auroral arcs
- what we don't know

Early References

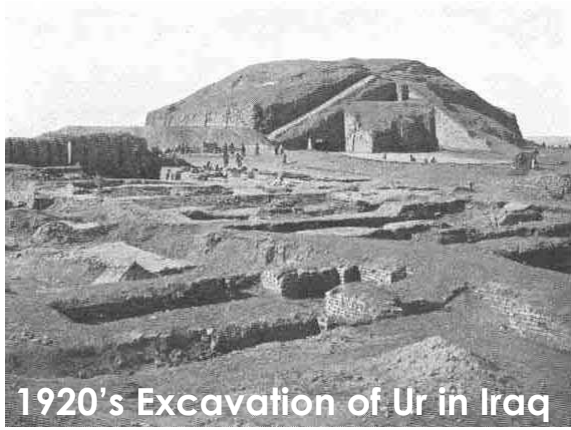


The mother of the Yellow Emperor Shuan-Yuan, Fu-Pao, saw a big lightning circuiting around the Su star of Bei-Dou (Ursa Major α) with the light shining all over the field. She then became pregnant. ***Chu-Shu-Chi-Nien***, Bamboo Album of Chronology, ~2600 B.C.

A northern god who is like a snake of red color who shines in the dark and whose name is Chu-Long (candle dragon). ***San-Hai Ching***, Book of Mountains and Seas, ~2200 B.C.

Early References

And it came to pass, that, when the sun went down, and it was dark, behold a smoking furnace, and a burning lamp that passed between those pieces. ***Abram's*** 1st covenant with the Lord as he was leaving Ur, Genesis 15:17, ~ 2000 B.C.


1920's Excavation of Ur in Iraq

And the work of the Lord came unto me the second time, saying, What do you see? And I said, I see a seething pot and its face is toward the north. ***Jeremiah***, 1:13, ~626 B.C.


Ezekiel's vision, Raphael, 1518

In the thirtieth year, in the fifth day of the fourth month, as I was among the exile on the bands of the river Chebar, heaven opened and I saw vision from God. ***Ezekiel*** 1:1-28, ~593 B.C.

Beliefs of Indigenous Peoples

The Finnish name for the northern lights "revontulet" is associated with the arctic fox. According to a folk tale, an arctic fox is running far in the north and touching the mountains with its fur, so that sparks fly off into the sky as the northern lights.

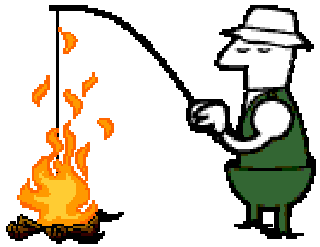
The Eskimos in the northernmost parts of Canada believe that the northern lights are created by spirits, which, dressed in the mystical light, are having fun because the sun is missing. Rapidly moving aurora were called the dance of death.

Other Eskimo groups have a myth of the northern lights as the spirits of the dead playing ball with a walrus head or skull.

Beliefs of Indigenous Peoples

Amrimen Fox Indians (Wisconsin) were afraid of the northern lights because they believed them to be the avenging souls of enemies they had killed.

The Menomini Indians (Wisconsin) believed that a benevolent giant was catching fish in the northern sea, using a fire.



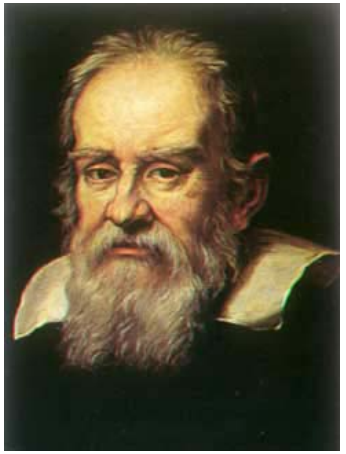
The Mandan Indians (North Dakota) explained the northern lights as fires over which the great medicine men and warriors of northern nations simmered their dead enemies in enormous pots.

Historical Observations

"A shocking prodigy that has been seen from Kuttenberg in the kingdom of Bohemia and also in other places nearby on January 12, 1570, from 4 hours into the night lasting until 8"

Historical Observations

- French scientist and philosopher **Pierre Gassendi** in 1621 named it the aurora borealis, meaning "***dawn of the north***"
  - Or it could have been **Galileo Galilei** in 1619



- Descartes – proposed aurora was caused by sunlight reflected from ice crystals in the air at high altitude

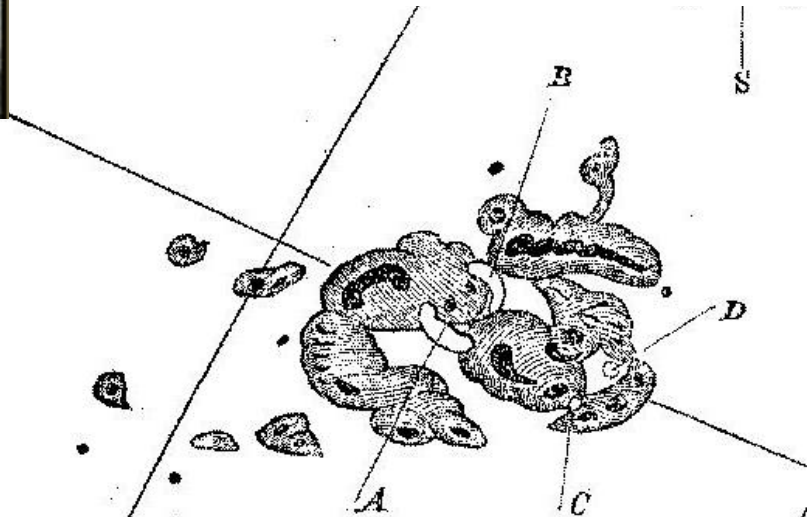
- Late 1600s – Edmund Halley – discovered auroral displays are ordered by direction of magnetic field

Historical Observations

1731 – French philosopher **de Mairan** suspected a connection between aurora and return of sunspots

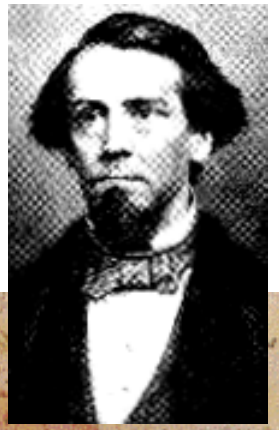
1741 – **O. Hiorten** with **George Graham** discovered that geomagnetic activity and aurora are connected

September 1, 1859 – **Richard Carrington**, sketching sunspot group was startled by white light flare. 18 hours later one of largest magnetic storms and aurora observed over Puerto Rico and magnetic disturbances in London.

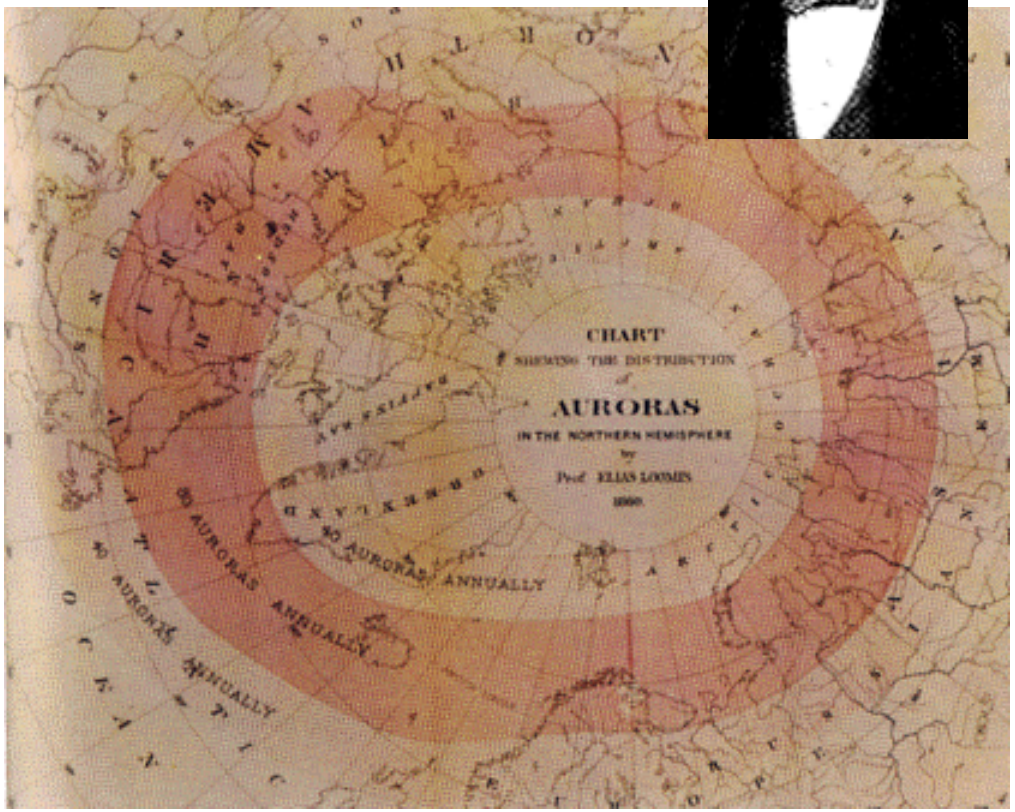


*Reproduction of a drawing by R.C. Carrington, showing the location of the flare he observed while making a drawing of an active region. Reproduced from his 1860 paper in Monthly Notices of the Royal Astronomical Society (vol. **20**, p. 13).*

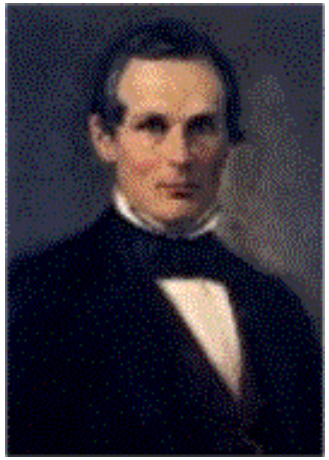
Historical Observations



Map of the frequency with which aurora is seen in various polar regions, produced in 1860 by **Elias Loomis** (1811-1889), professor of natural philosophy at Yale. The central band has at least "80 auroras annually".

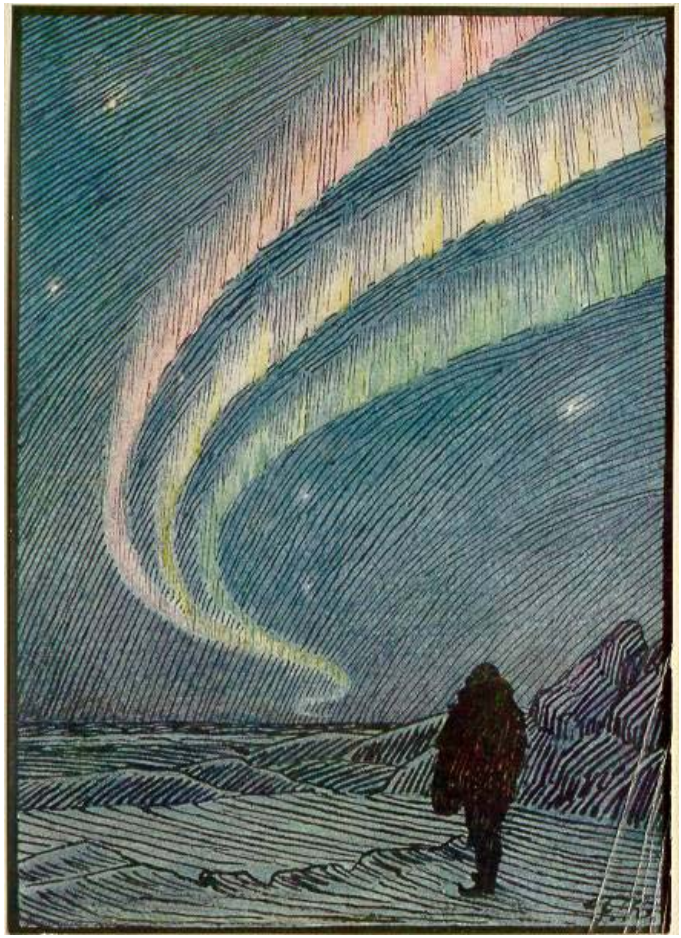


Historical Observations



In 1868 **Anders Jonas Ångstrom** of Sweden uses a prism to show that auroral light differs from sunlight.

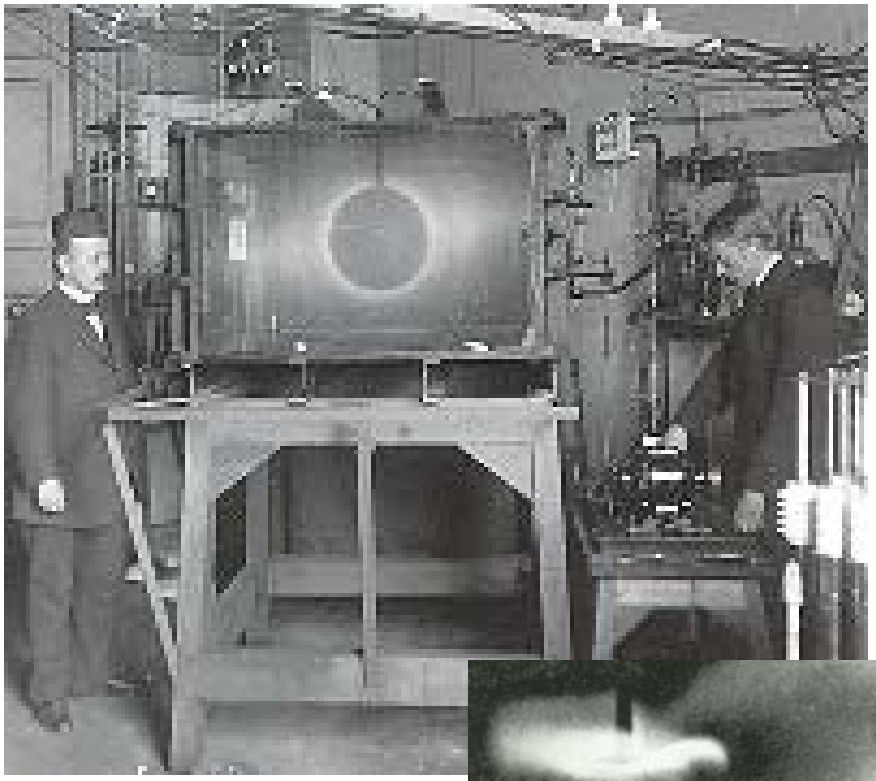
In 1910, **Carl Störmer** used triangulation to determine that the height of the aurora is around 100 km

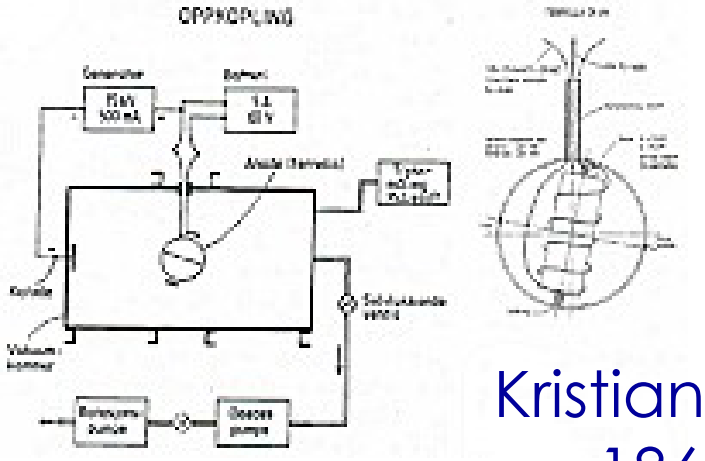


Frontispiece from *In Northern Mists* (1912), Woodcut by Fridtjof Nansen.

Start of modern research

1st International Polar Year 1882-83





Kristian Birkeland
1867-1917

Start of contemporary research
1st International Geophysical Year 1957

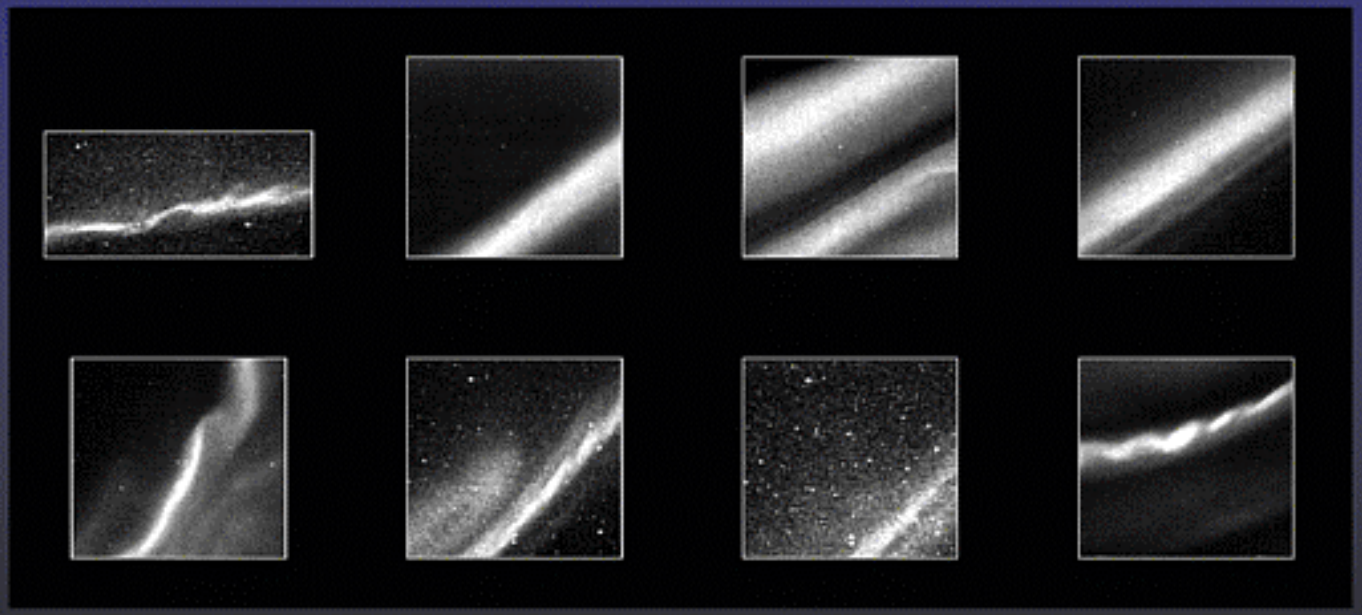
Chapman - recognized that the Earth's magnetic field would create a cavity in the plasma outflow from the Sun

Sydney Chapman (1888-1970)

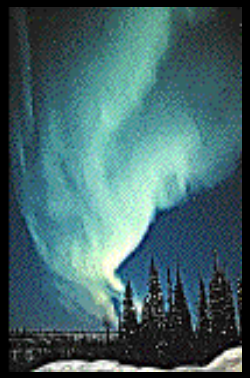
Alfvén – recognized that the electric fields would produced by the solar wind flowing across the magnetic fields – used MHD

Hannes Alfven (1908-1995)

Examples of Discrete Auroral Structures (.1 - 1 km wide)

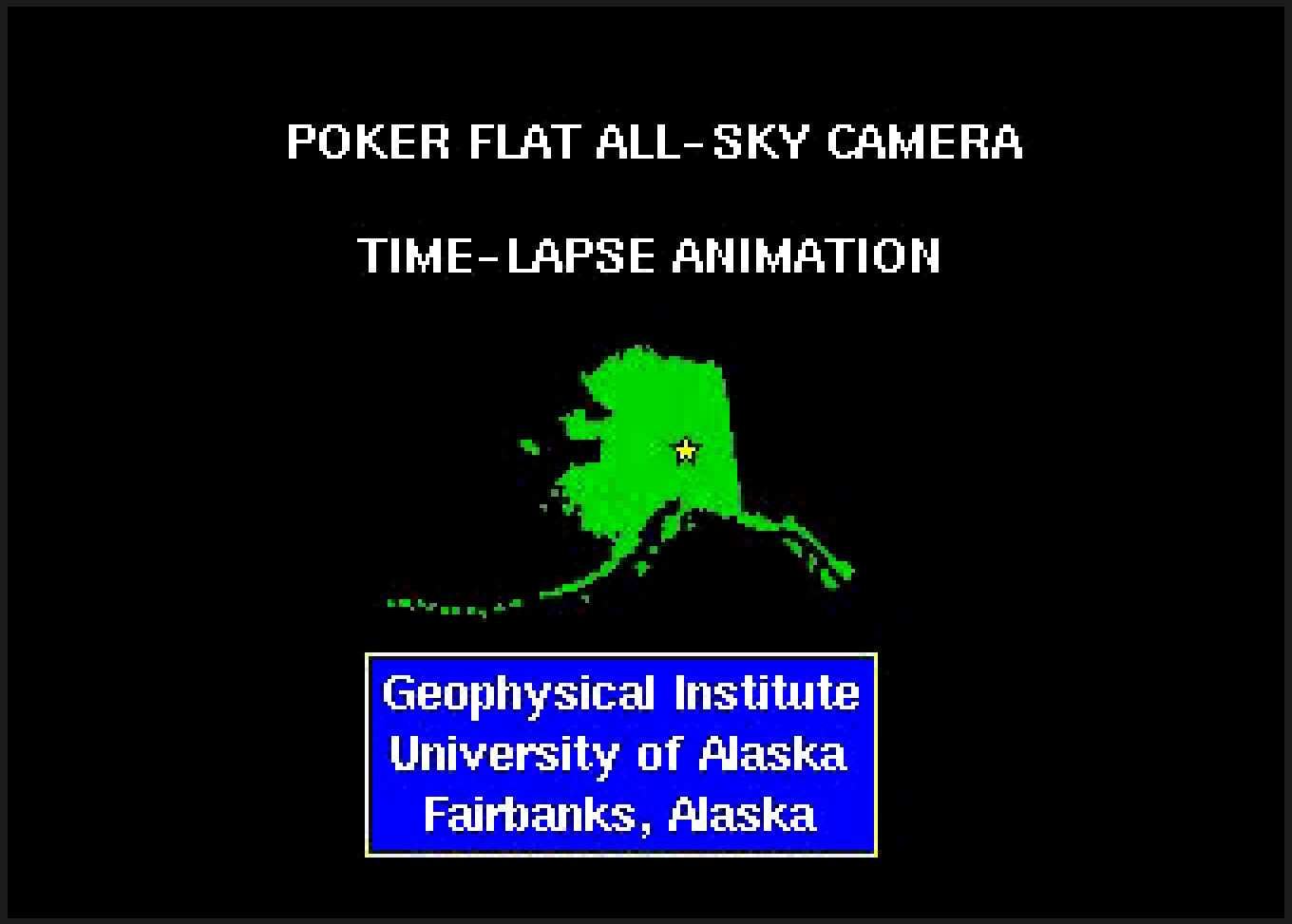



(C) 2003 JEFF PEDERSON



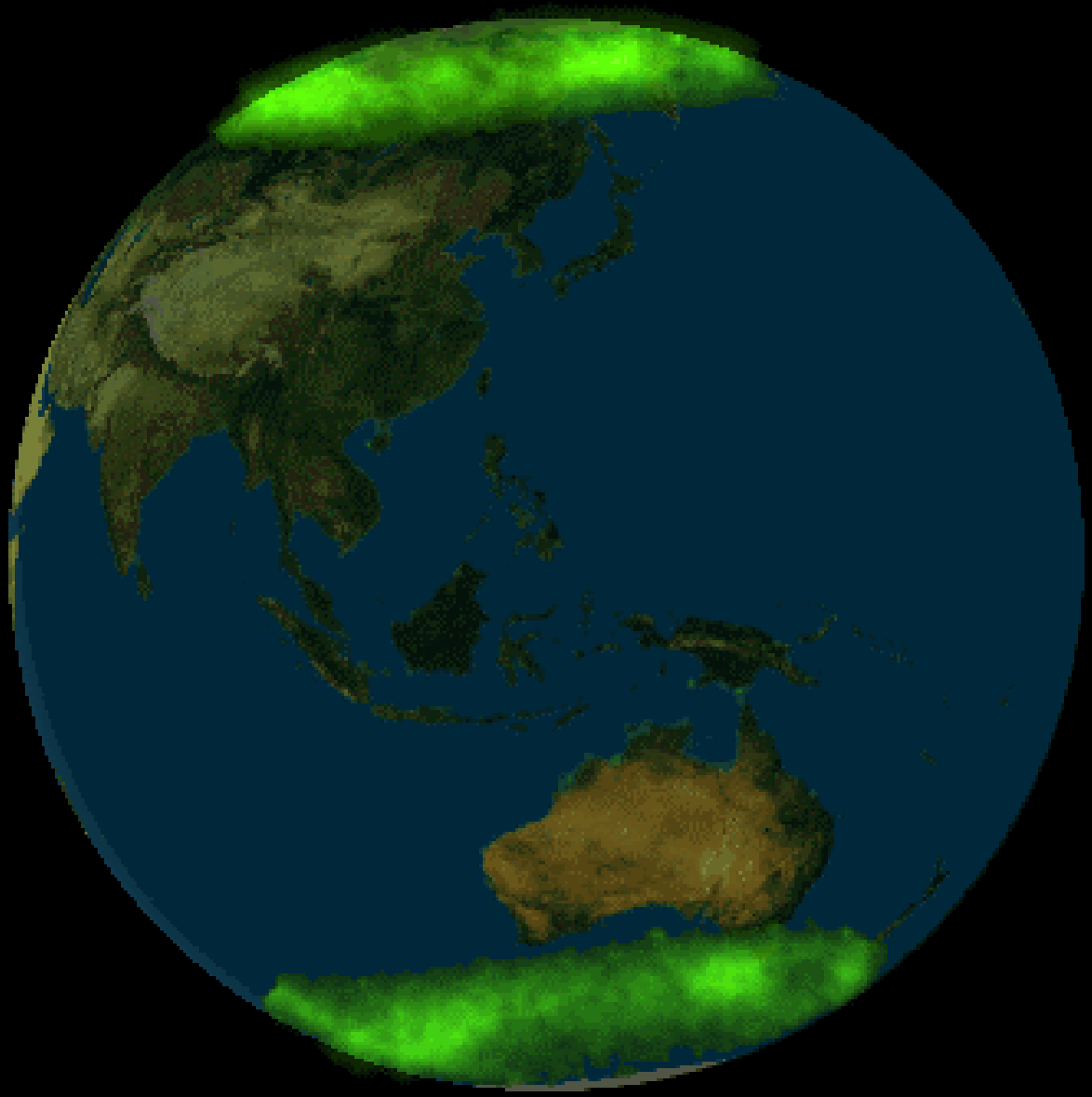
March 11,1998 - This gif consists of 13 2 second exposures. The reason for the light change in the foreground and on trees is the rotating beacon flashing 1 white and 1 green light.

April 5, 2000 - This gif consists of 35 3 second exposures. The storm was seen by many people north of 40 degrees.



January 6, 2000

From low Earth orbit (Shuttle)



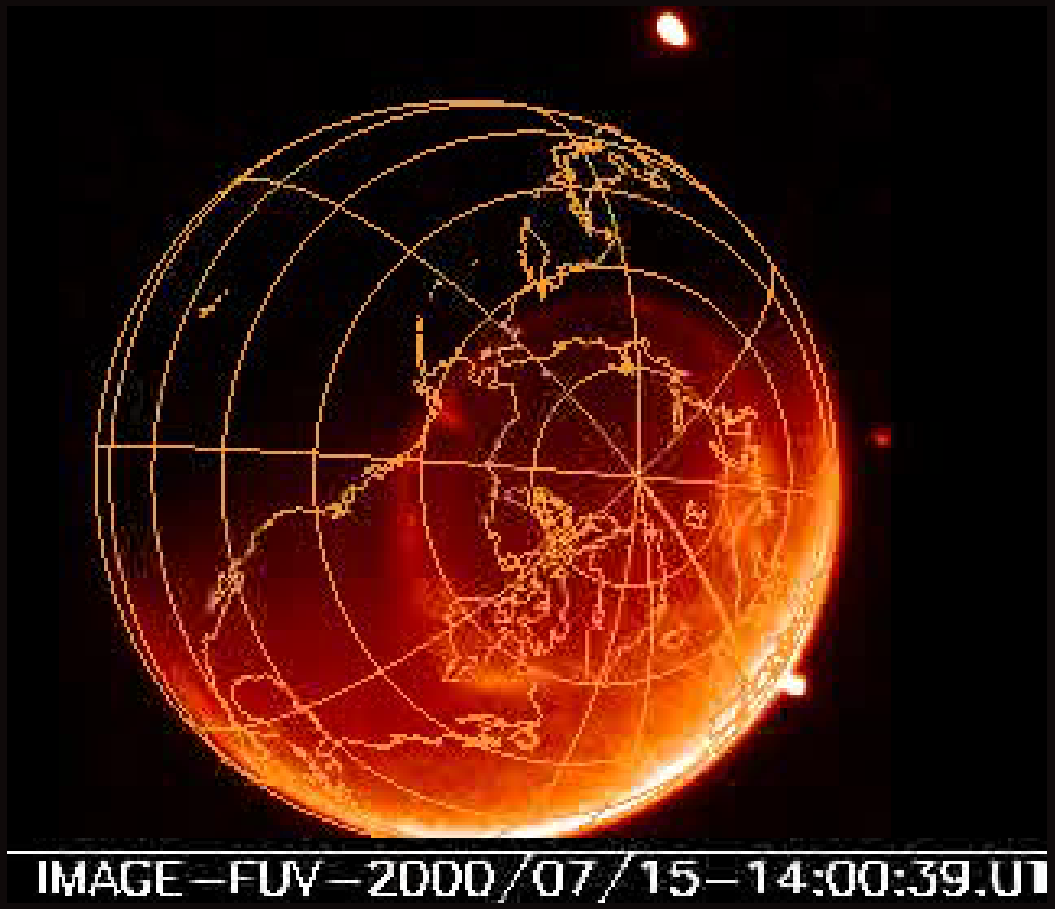
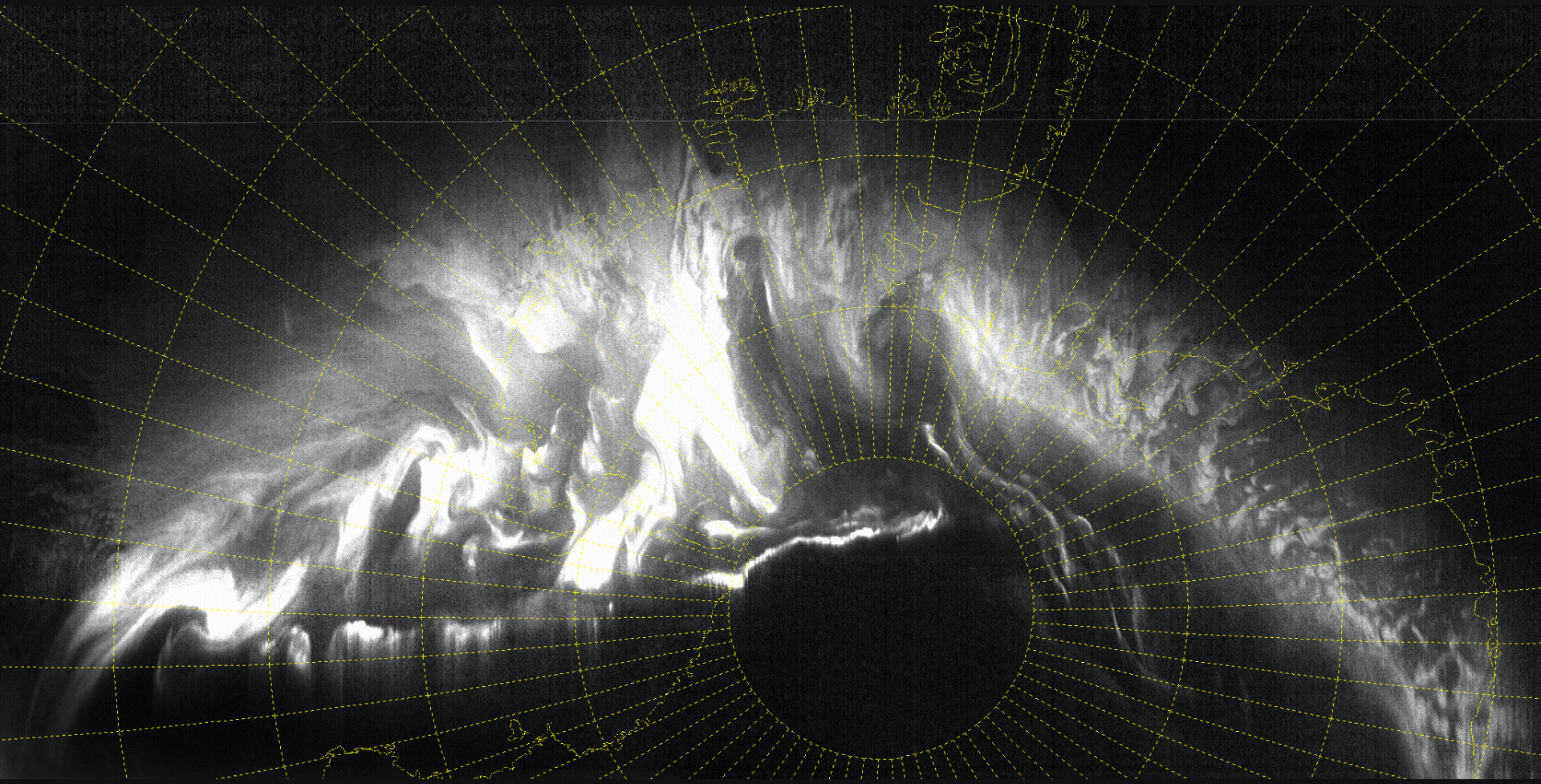
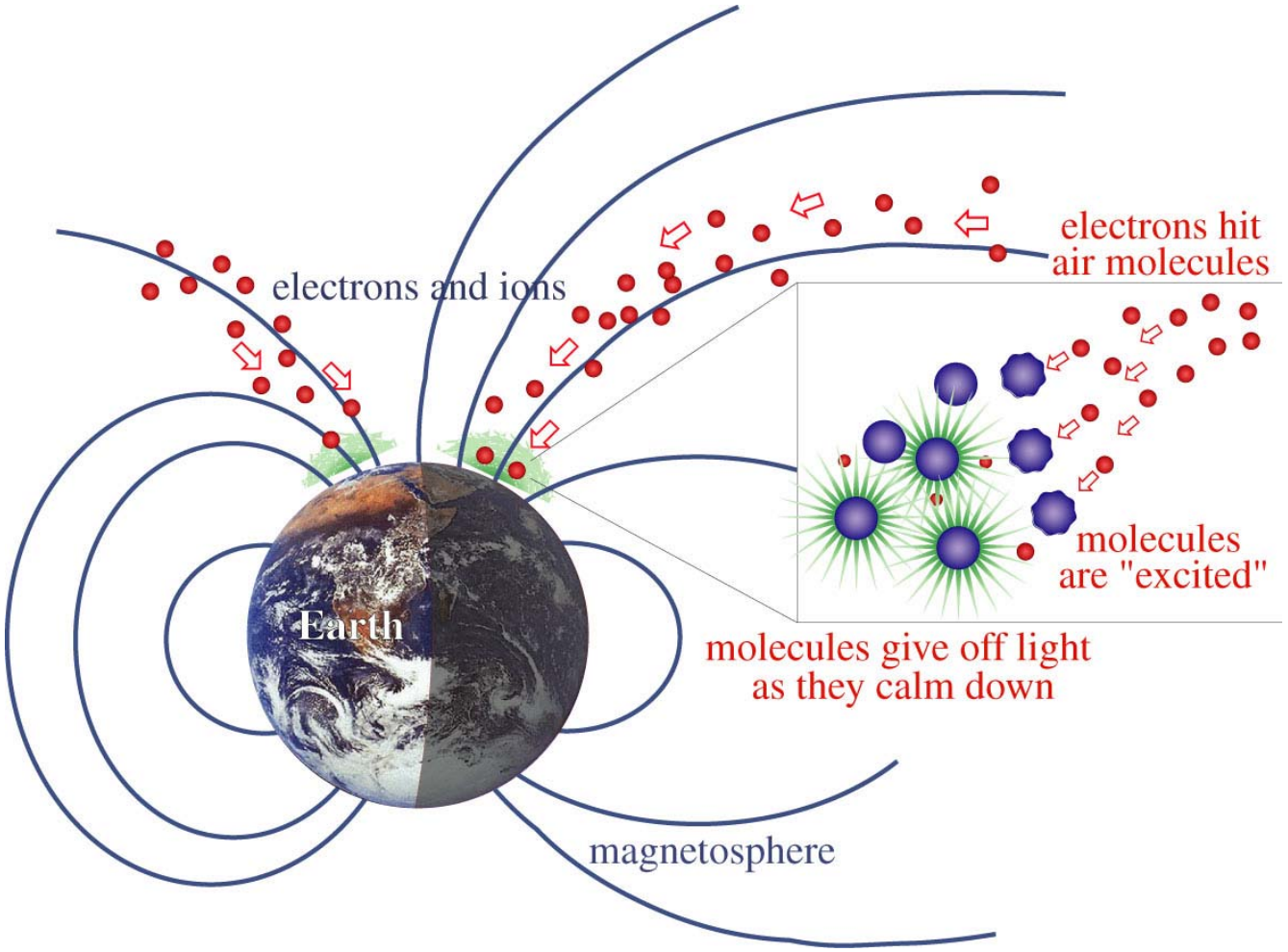


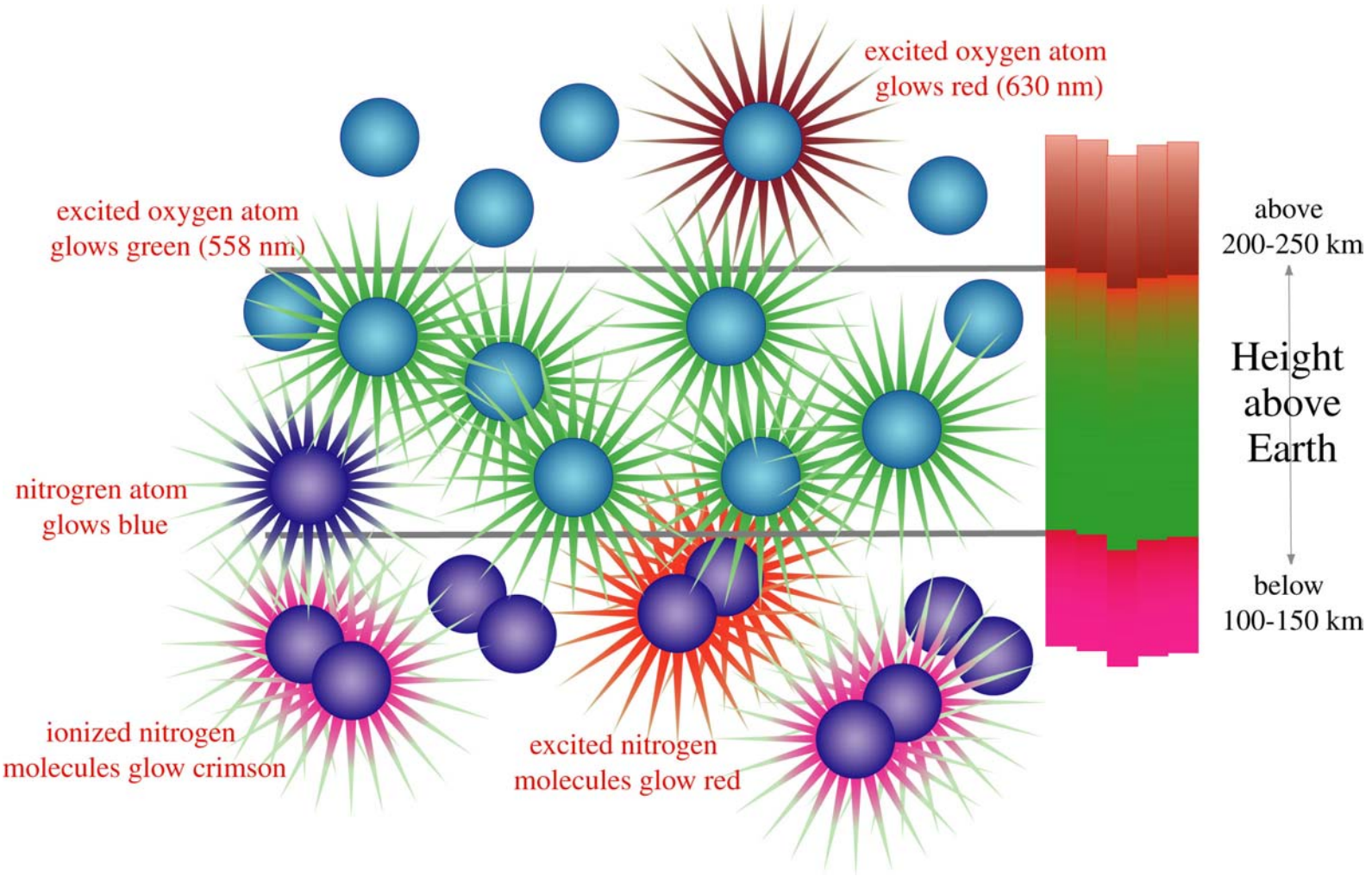
IMAGE – FUV – 2000/07/15 – 14:00:39.UT

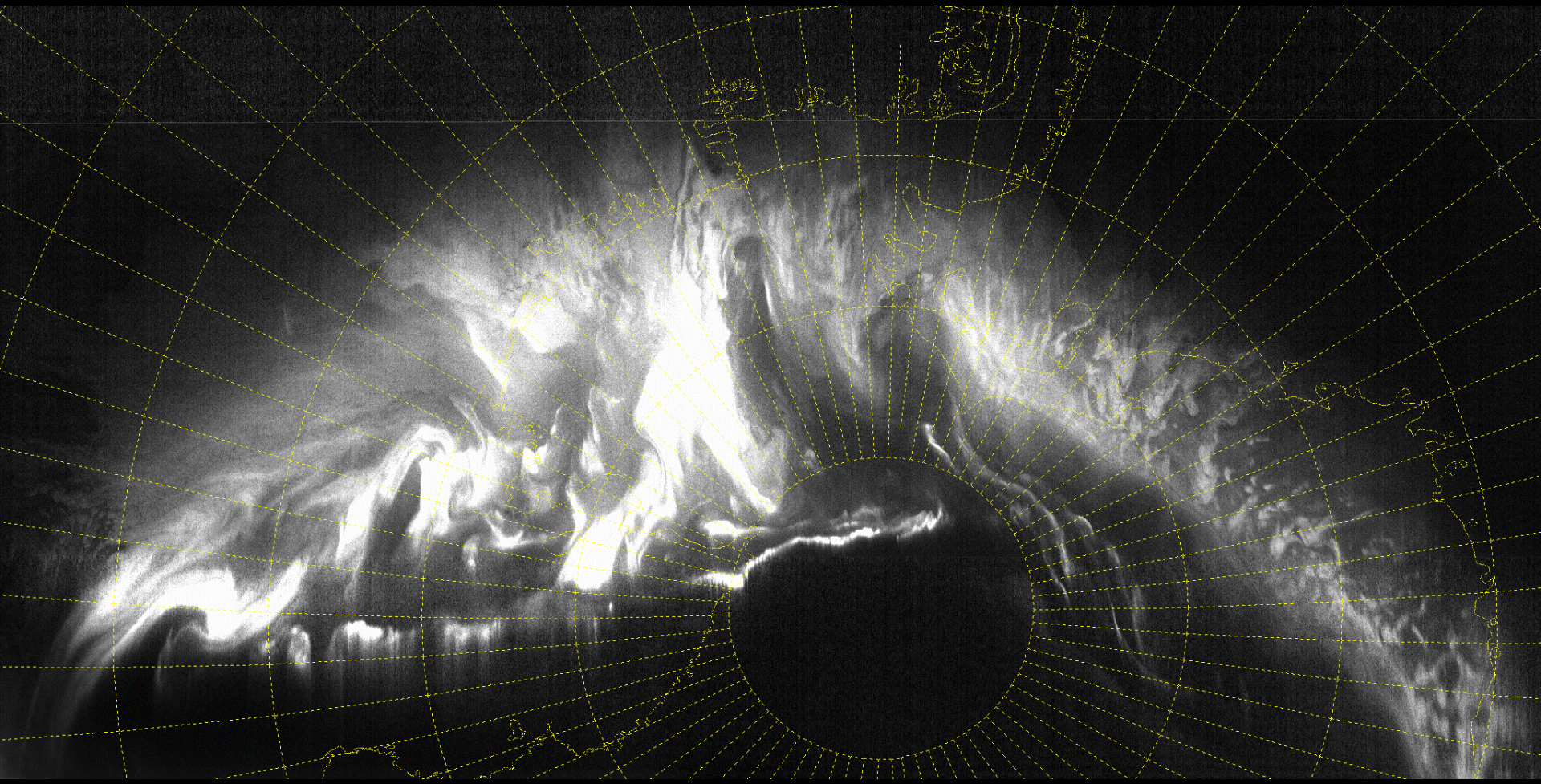


What Causes the Aurora Emissions?

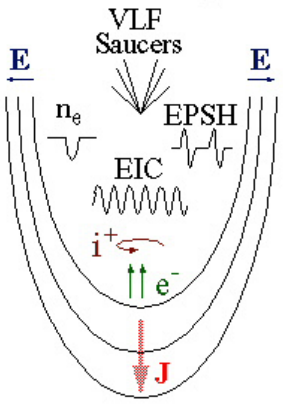


What Causes the Auroral Emissions?



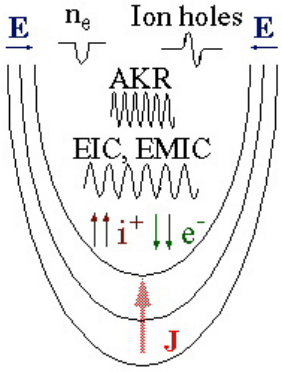


Downward Current Region



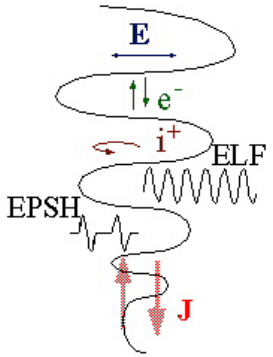
1. Downward current. ↓↓ J
2. Diverging electric field structures. E E
3. Small-scale density cavities. n_e
4. Up-going, field-aligned electrons. ↑↑ e^-
5. Ion heating transverse to ***B***. Energetic ion conics. i^+
6. ELF electric field turbulence. Ion cyclotron waves.
7. 3-D Electron phase-space holes.
8. VLF saucer source region.

Upward Current Region



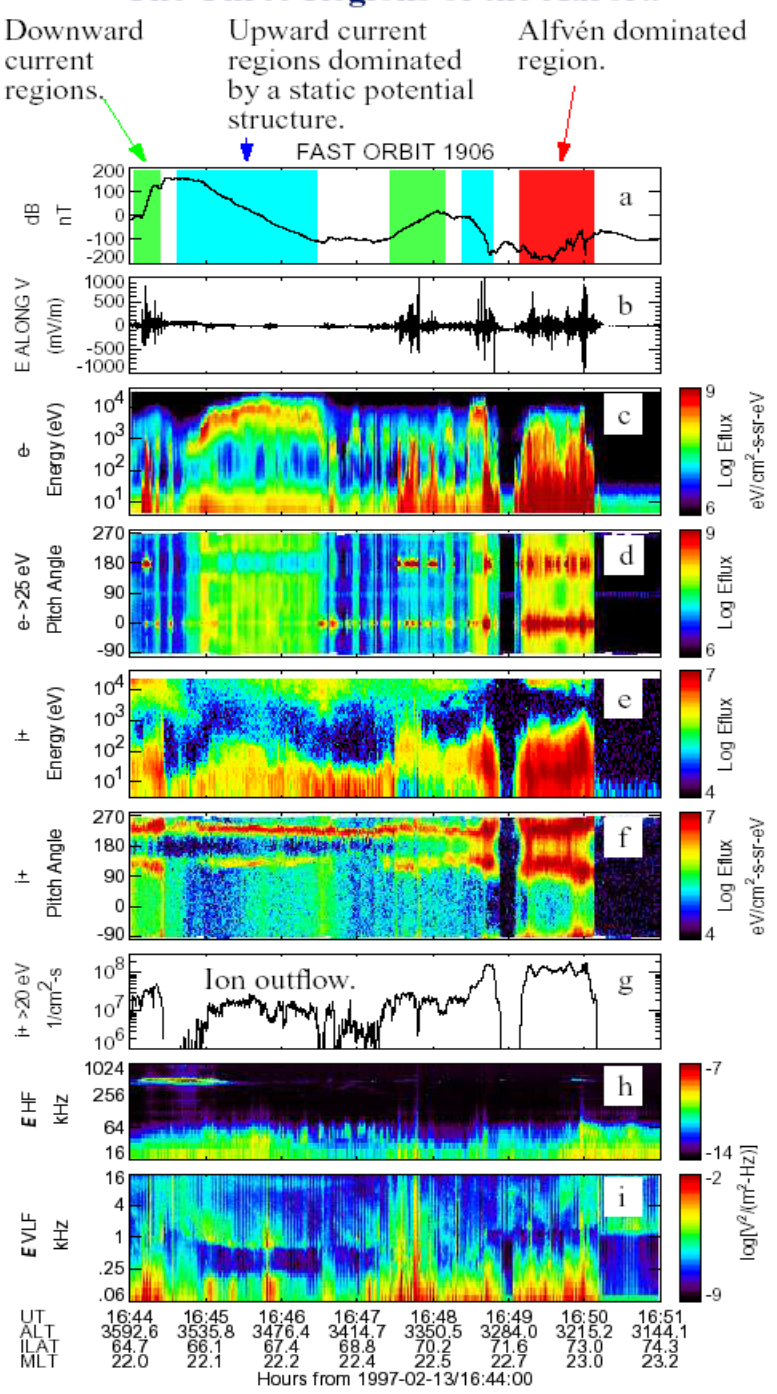
1. Upward current. ↑↑ J
2. Converging electric field structures. E E
3. Large-scale density cavities. n_e
4. Down-going, inverted-V" electrons. ↓↓ e^-
5. Up-going ion beam. Ion conics. ↑↑ i^+
6. Large-amplitude ion cyclotron waves and electric field turbulence.
7. Ion holes. Nonlinear ion cyclotron waves.
8. AKR source region.

Polar Cap Boundary Acceleration Region

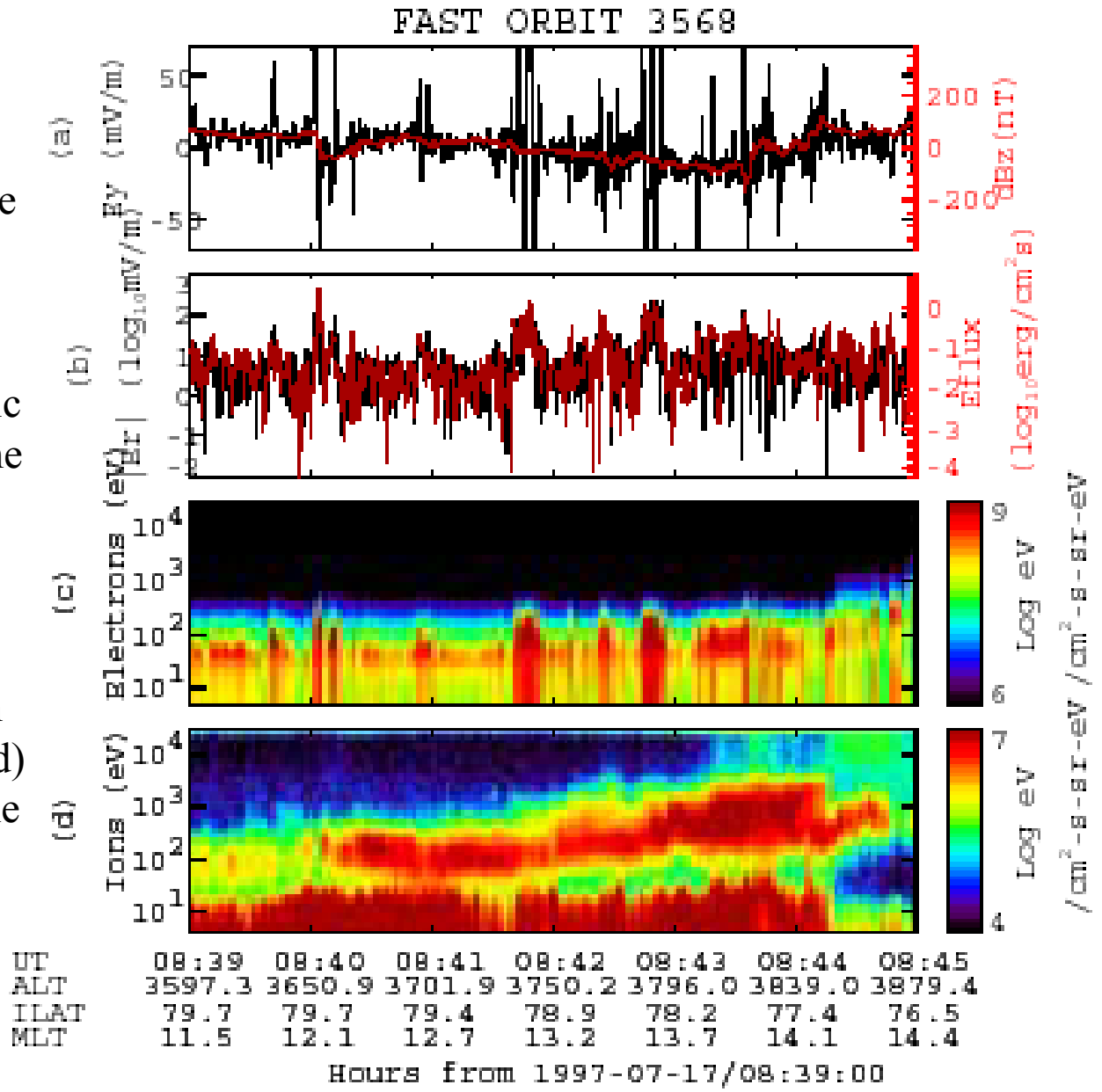


1. Filamentary Currents. ↓↑ J
2. Alfvénic electric fields. E
3. Density turbulence.
4. Counter-streaming electrons. ↑↓ e^-
5. Ion heating transverse to B. Intense ion outflow. i^+
6. ELF electric field turbulence. Ion cyclotron waves.
7. 3-D Electron phase-space holes.

The Three Regions of the Aurora



The polar cap boundary near the cusp region (dayside). (a) DC electric field measurement (black) along the spacecraft trajectory(dawn-dusk); magnetic field perturbation (red) along the spin axis (sunward). (b) Amplitude of small-scale electric field (black); field-aligned electron flux (red). (c) Burst-like electron structures in the energy-time spectrogram. (d) Ion structures in the energy-time spectrogram. The classic dispersion signature includes "steps". The ions below ~100 eV are flowing anti-earthward.



Upward current regions

- Down going accelerated electrons
- Up going accelerated ions
- Dc electric field structures
- Bounded by strong converging e-fields that surround a low density cavity
- Cavity is where intense radio beacon is produced called Auroral Kilometric Radiation (AKR)
- Also electromagnetic ion cyclotron waves (EMIC) and ion solitary waves (EIC)
- Auroral emissions
- Scale 10's of km
- Several seconds to many minutes/hours

Downward current regions

- Upward accelerated electrons
  - Large flux 10^8- $10^9 cm^{-2}s^{-1}$, low energy < 1keV
- Outflow of ions
  - Higher fluxes and energy
- Intense low frequency plasma wave emissions
- Near equatorward edge of oval, down flowing ion beams

Alfvén wave driven regions (dynamic auroral arcs)

- Highly structured regions where particle acceleration is dominated by waves rather than by quasi static potential structures
- These regions consist of recently reconnected field lines in which the magnetospheric plasma has not come into equilibrium with the ionosphere
- In this region, Alfvén waves are observed to be exchanged between the ionosphere and magnetosphere. These carry the energy needed to achieve lowest energy state.

Alfvén wave driven regions

- Filamentary nature
  - A few km
  - Near local noon and midnight
  - Simulations indicate very bright, 100 KR
- Alfvén waves produce cascade of energy that results in very bright aurora
- Large ionospheric outflow
  - Lower energy, larger fluxes $10^{10} cm^{-2} s^{-1}$ relative to downward current regions
- Counter streaming electrons, little current
- **E** and **B** fluctuations – 0.1 to 10 Hz
- 10 KeV electrons, 100 ergs/cm^2-s fluxes

Upward current arcs

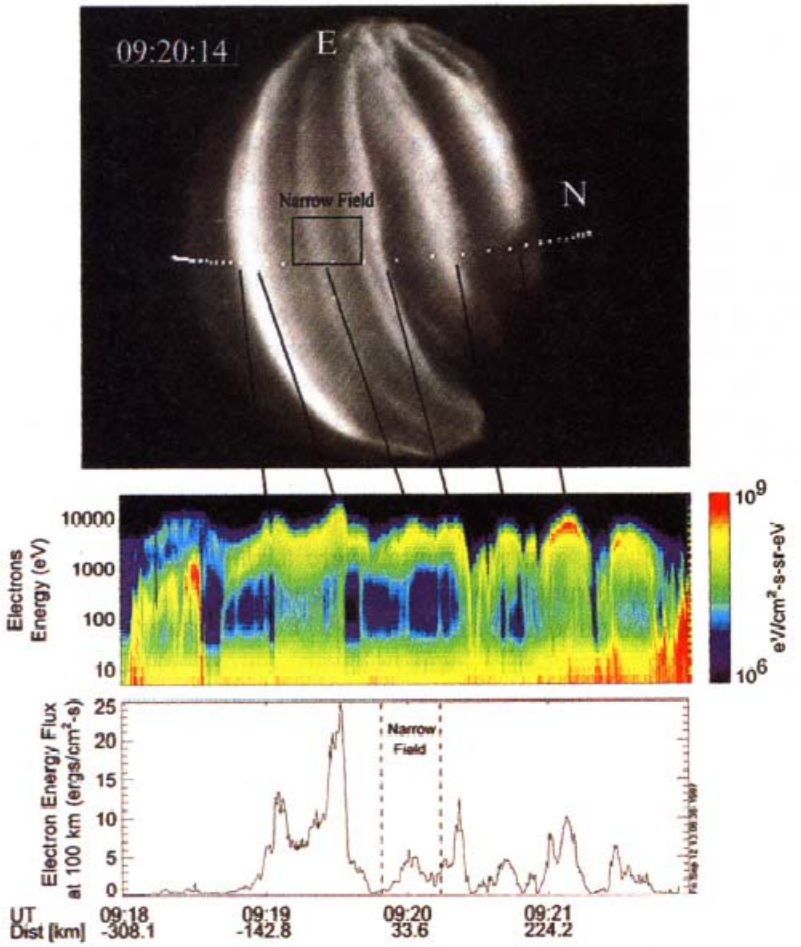
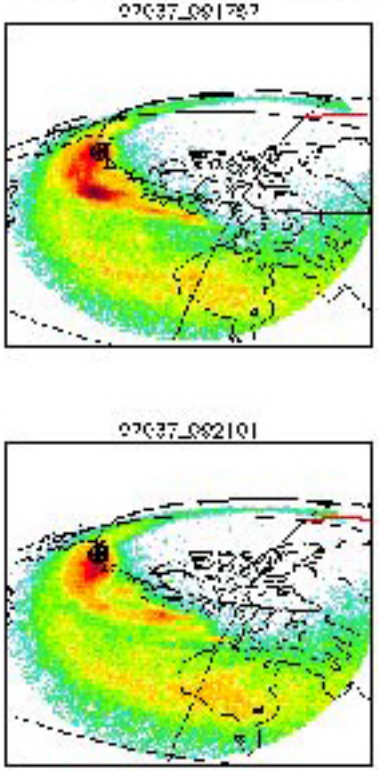
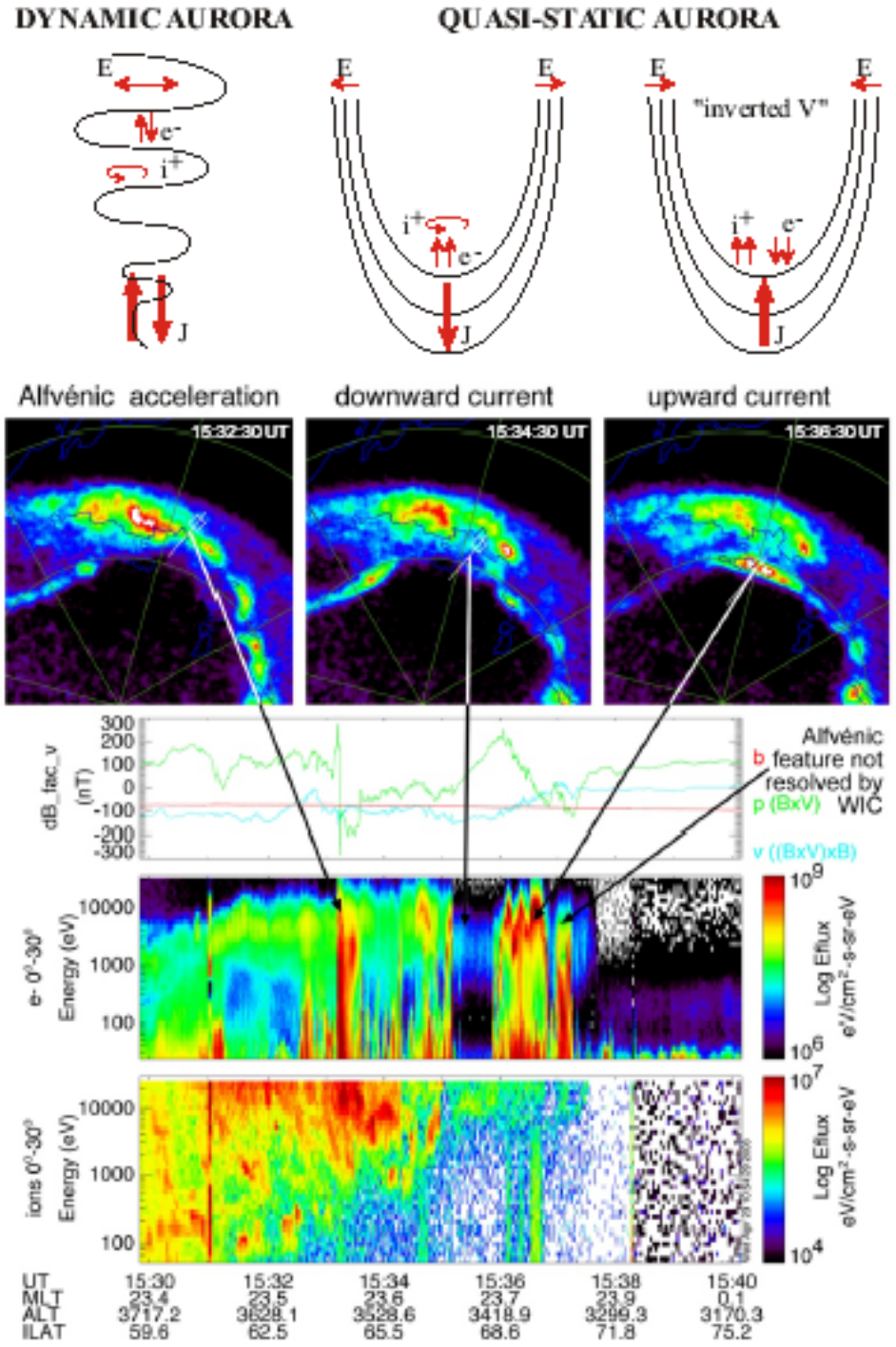
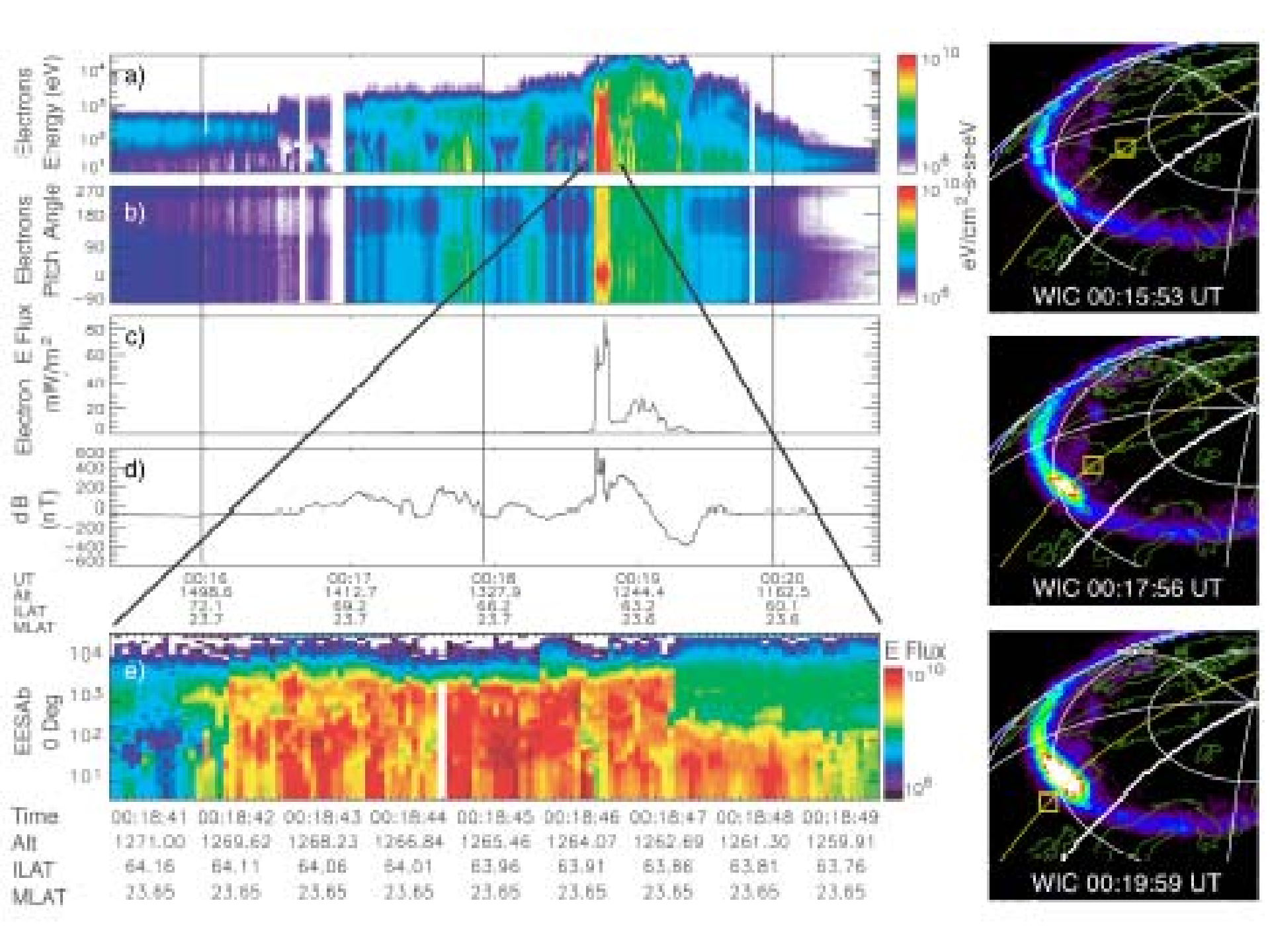


Figure 2. Multiple arcs as seen in the all sky image and by FAST. The 110 km conjugate is shown at 10s intervals as FAST passed across from left to right. The center panel is a "normal" format of the electron energy spectrum (integrated over all pitch angles) and shows a number of inverted-V structures. The bottom panel is the precipitated energy flux on a linear scale. The narrow auroral arcs are clearly displayed here. The auroras, in particular the two arcs to the right (north) did change over the 4 minutes of the pass. The pass was near 21:20 magnetic local time. Dist is the distance along the conjugate track from the left edge of the narrow field image (figure 3).

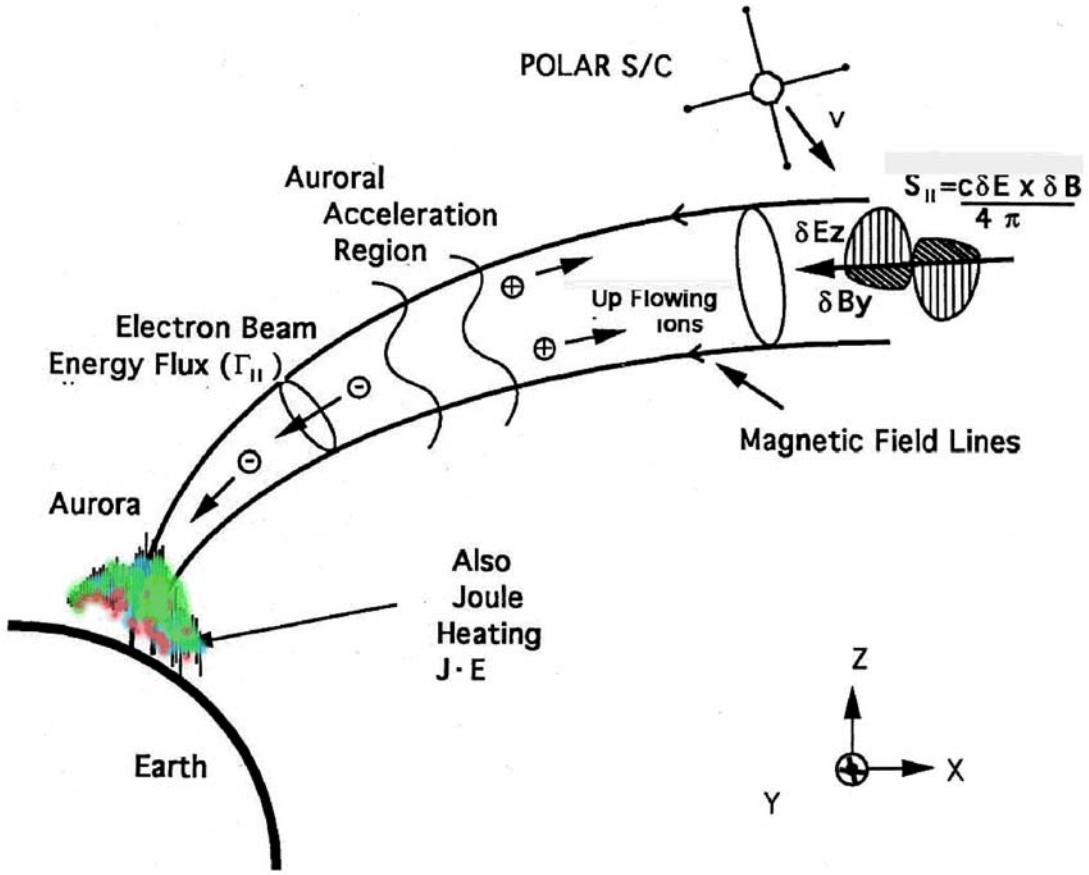
UVI images of Feb 6, 1997 with cross locating 69.6 N, 148.54W, approximate location of all-sky image from Stenbaek-Nielsen et al.




DYNAMIC AURORA
QUASI-STATIC AURORA
E
e⁻
i⁺
J
"inverted V"
Alfvénic acceleration
downward current
upward current
15:32:30 UT
15:34:30 UT
15:36:30 UT
dB_fac_v (nT)
300
200
100
0
-100
-200
-300
Alfvénic
b feature not
resolved by
p (BxV) WIC
v ((BxV)xB)
e- 0°-30°
Energy (eV)
10000
1000
100
10⁹
10⁶
Log Eflux
e⁻/cm²-s-sr-eV
ions 0°-30°
10⁷
10⁴
eV/cm²-s-sr-eV
UT 15:30 15:32 15:34 15:36 15:38 15:40
MLT 23.4 23.5 23.6 23.7 23.9 0.1
ALT 3717.2 3628.1 3528.6 3418.9 3299.3 3170.3
ILAT 59.6 62.5 65.5 68.6 71.8 75.2


a)
Electrons Energy (eV)
b)
Electrons Pitch Angle
c)
Electron E Flux mW/m²
d)
dB (nT)
UT
All
ILAT
MLAT
00:16 1498.6 72.1 23.7
00:17 1412.7 69.2 23.7
00:18 1327.9 66.2 23.7
00:19 1244.4 63.2 23.6
00:20 1162.5 60.1 23.6
e)
EESAb 0 Deg
E Flux
eV/cm²-s-sr-eV
WIC 00:15:53 UT
WIC 00:17:56 UT
WIC 00:19:59 UT
Time 00:18:41 00:18:42 00:18:43 00:18:44 00:18:45 00:18:46 00:18:47 00:18:48 00:18:49
All 1271.00 1269.62 1268.23 1266.84 1265.46 1264.07 1262.69 1261.30 1259.91
ILAT 64.16 64.11 64.06 64.01 63.96 63.91 63.86 63.81 63.76
MLAT 23.65 23.65 23.65 23.65 23.65 23.65 23.65 23.65 23.65

Same mechanism that powers aurora



Same mechanism that powers aurora

Wygant et al., 2000, find that the dominant form of energy incident on auroral acceleration regions is due to intense Alfvén waves propagating down magnetic field lines

Observations:

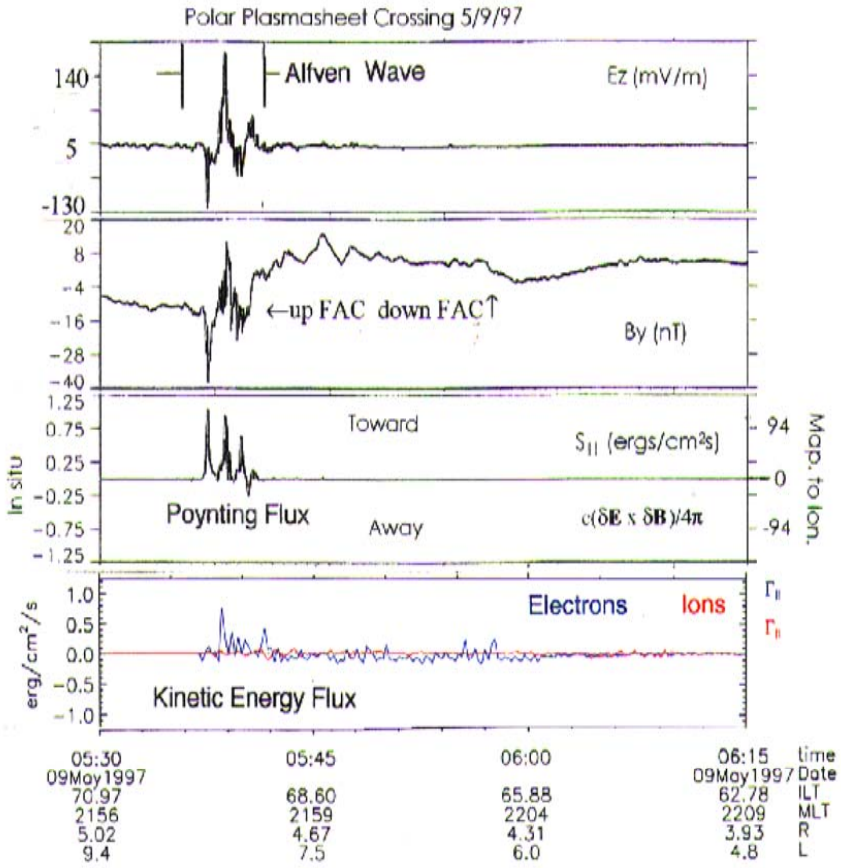
Shown are the Alfvén wave **E** and **B** fields along with the Poynting Flux due to the wave as it flows towards Earth at ~10,000 km/s.

As the wave propagates toward earth, it becomes more intense as the magnetic field lines converge. It is this energy that powers the aurora.

Peak values of the measured energy flux are 1 erg/cm^2-sec at the altitude of the spacecraft.

Mapped to ionospheric altitudes, the energy flux is greater than 100 ergs/cm^2-sec.

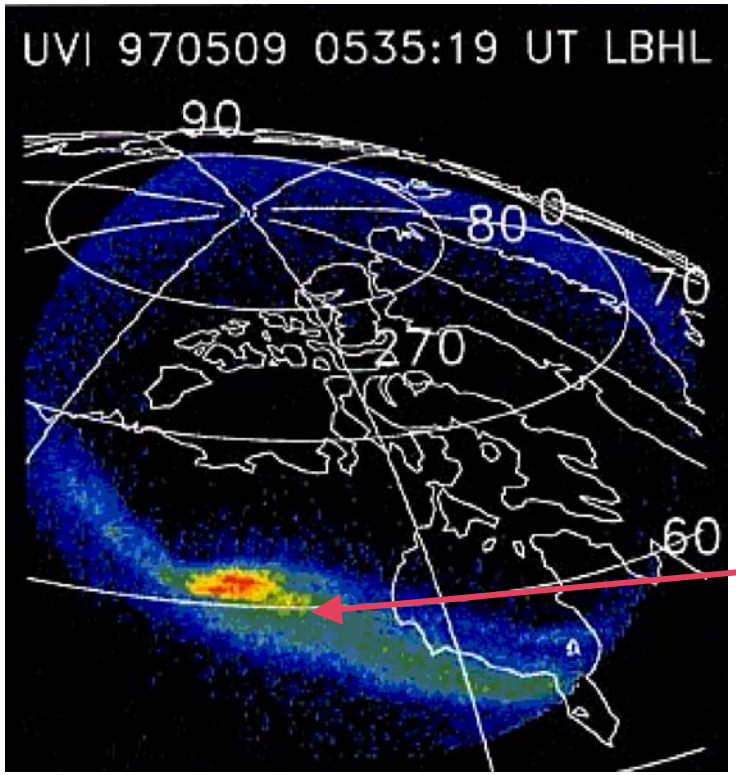
A barely visible aurora requires only about 1 erg/cm^2-sec.

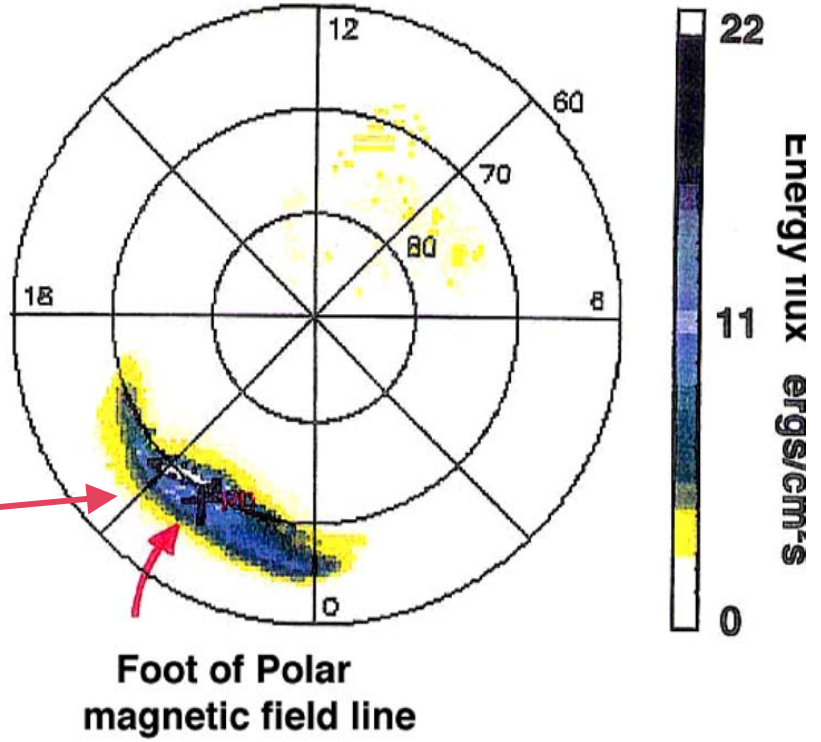


Wygant et al. Discovers the Energy Source Powering the Aurora

This UV image of the aurora was obtained at the same time that POLAR measured the intense Alfvén wave associated energy flux.

The aurora was most intense near the foot of the POLAR magnetic field line and has an energy of >30 $ergs^2s^{-1}$ – a very intense aurora.





Open questions

- Do these Alfvén wave driven arcs evolve from the quasi static arcs, or vice versa?
- Is the Alfvén aurora driven by larger scale features in the magnetosphere or are they controlled by local acceleration or instability processes?
- What affect does the ionosphere have on the generation of the arcs?
  - Alfvén resonators, conductantces, Joule heating
- How are the dynamic arcs related to a variety of magnetospheric phenomena
  - dayside merging, reconnection, substorm onset, bursty bulk flows of plasma in the tail

So what is needed?

- Continuous observation of these features for several seconds (~10) with the time and space resolution (0.1 sec / 1 km) and energy discrimination (>5 keV or <1 KeV) to observe their evolution
- Combination of multispectral remote and in situ measurement on comparable time scales